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The Natural Theology of the Doctrine of the Forces.

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THE NATURAL THEOLOGY OF THE DOCTRINE OF THE FORCES.

By Prof. Benjamin N. Martin, D. D., L. H. D.,
University of the City of New York.

The great change which has passed over the philosophy of physics in our day, relates to the doctrine of the forces; and scientific teaching now affirms the correlation, or convertibility, of them all.

The idea of force, which lies at the basis of this view, is yet far from being clearly defined in the conception of the physical philosopher. It is vaguely conceived as something lying back of phenomena, to which the latter are to be referred as their ground or cause. All the varied phenomena of the physical world, and, indeed, of the physical universe, are attributed, not as recently they were, to imponderable fluids or agents, but to motions of the masses, or the particles, of matter; motions which are themselves due to the action of certain impelling forces. The chief interest which attaches to the subject arises from the apparently successful attempts that have been made to convert one of these forces into another, and thus to arrive at a generalization which will admit of our grouping them together, as forms or manifestations of a single force.

The great physical agencies of our world, light, heat, electricity, and the chemical force (known now as chemism), are so unlike in their ordinary aspects, that, during all the earlier stages of our inductive progress, not only was their nature unknown, but their unity, their common character, was unsuspected. Light was regarded as a peculiar emanation from a certain class of bodies called *luminous;* heat was a kind of fluid filling the pores of bodies, and capable of being squeezed out of them by compression, as water from a sponge; of electricity, it was long disputed whether it consisted of one fluid, manifesting its presence by excess and defect, or of two fluids of opposite character, which give respectively the vitreous and the resinous electricities; magnetism was conceived to be due to a fluid acting from one pole of a magnet to another, in curved lines; galvanism was deemed to be a fluid closely related to the nervous fluid of the human system; and in addition to all these we had the force of

chemical affinity, governing, in a manner that was deemed entirely peculiar, the chemical reactions. It was long before any common ground in all these apparently diverse agencies was even suspected; but within a recent period a change has passed over these modes of conceiving of the imponderable agents of our general chemistry.

It began to be understood that light was not a distinct substance sent forth in radiating lines, but a vibration or regulated motion, in a universally diffused medium of the rarest kind, a motion analogous to that vibration of the air which reports itself to the ear as sound. By this discovery, one of the great supports was stricken from an erroneous mode of conceiving.

Early in the present century, however, the mutual relations of some of these agencies began to be more clearly perceived. Galvani's original discovery, made in 1790, that a movement can be excited in the limbs of an animal by the application of two metals to the nerve and the muscle, was made in connection with the conductor of an electrical machine; and was originally announced as a kind of animal electricity; and this connection, "at first rather conjectured than proved, succeeding researches confirmed."* Ten years after, in 1800, Volta contrived—by means of the instrument which was named, from its inventor, the voltaic pile—to accumulate this force so as to bring it much more fully within the sphere of observation. The general attention of observers was thus fixed upon the very interesting phenomena of voltaic electricity, and many wonderful properties and beautiful laws were brought to light. The discovery in 1820, by Oersted, of Copenhagen, that the conducting wire of a voltaic circuit affects the magnetic needle, brought prominently forward the idea of the connection of these forces; and the term *electro-magnetic* marks the step which identified the two as really forms of one, so that electricity, magnetism, and galvanism, became inseparably connected in scientific thought as manifestations of a single agency.

Contemporaneous with this, was the brilliant epoch of Davy and Faraday. It had been found that under the influence of the voltaic circuit certain compound substances are decomposed. Water, for instance, was resolved into its elementary gases; and some metallic salts suffered a like resolution into their constituent elements. Davy felt assured that not only these, but the whole body of the voltaic phenomena, are chemical in their nature; and in 1806 he uttered

* Whenell's Hist. of the Inductive Sciences.

his thought, more as a conjecture than a discovery, "that chemical and electrical attractions were produced by the same cause, acting in the one case on particles, and in the other on masses."*

This anticipation of Davy's was taken up by his successor, Faraday, who proved that the electric current in a voltaic pile is due to "the mutual chemical action of its elements." He introduced a distinctness of conception, and an accuracy of expression, which contributed greatly to the elucidation of the subject. He showed that the wire of a voltaic circuit "conducts chemical affinity," and that "electricity is only another mode of the exertion of chemical forces."† By his researches, principally, the identity of chemism with the various forms of electricity, was established; and we have, as the great result of Faraday's labors, the science of *electro-chemistry*.

Meanwhile, in other departments, a similar progress was going on. Not only was the theory of light reduced to the simple conception of the regular and rapid movement of particles of a rare medium, but the conception of heat underwent an analogous change. It was found that the conception of a physical substance termed caloric, which had served, during all the last century, to explain and classify many of the phenomena, afforded only an imperfect and unsatisfactory account of them; and the attention of observers was directed to the subject in the hope of gaining some clearer ideas. Among the earliest of these investigators was our distinguished countryman, Count Rumford. A paper read by him before the Royal Society, in 1798, gave account of a very remarkable and happy experiment, which elucidated the nature of heat, so far as to show that it could not be a distinct substance. He had been struck by the very great amount of heat generated by the mechanical process of boring cannon; and that process gave him the idea for his experiment. He took a thick metallic cylinder, and immersing it in water at a temperature of 60°, applied to it a metallic plunger, which was firmly pressed against the end of it, while the cylinder itself was steadily turned by horse-power. At the end of an hour, the temperature of the water had risen to 107°; in thirty minutes more it reached 140°; at the end of two hours the mercury stood at 178°; at two hours and twenty minutes it was 200°; and at two hours and thirty minutes the water, which amounted to two and a half gallons, actually boiled. "It would be difficult," he says, "to

*Whenell's Hist. of the Inductive Sciences. †Ib.

describe the surprise and astonishment expressed in the countenances of the bystanders on seeing so large a quantity of water heated, and actually made to boil, without any fire."*

This experiment ought to have been decisive against the theory of the material nature of heat, but, for a long time, it failed to attract the attention which it deserved; and only recently, by the confirmatory experiments of Joule, in England, did it reach the rank to which it was entitled. It shows us that heat—a thing which can be supplied inexhaustibly by the simple friction of a borer—is not any material substance, however attenuated, but must be conceived as a peculiar mechanical condition of the particles of matter. This general view I need not dwell upon. It has been illustrated with so much ability and interest by Tyndall, in his Lectures on Heat, that it suffices to refer to his book for the complete elucidation of the subject. Heat is now understood to be a rapid motion of the particles of any substance—of what nature we do not yet accurately know—but this, unquestionably. In heating a substance, we do but put its particles into a state of rapid, perhaps vibratory, motion; an elevation of temperature means an increase of this movement, either in *rapidity* or in *extent*, or in both; and a lowering of temperature means a diminution of the amount of this motion.

Now this internal motion of the particles of any body, is found to sustain a relation to the mechanical motion of the mass as a whole; and the one of these motions is convertible into the other. When a ball is dropped from a height upon a solid body, and its motion suddenly arrested, the ball becomes heated; that is, the mechanical motion of the mass, its transfer by a molar force from place to place, is changed into a motion of the particles among themselves. These are thrown into rapid *vibration*, we will call it, for want of a more accurate name; that is, the temperature of the body is raised. If we hammer a piece of iron, it becomes hot; the arrested mechanical motion of the hammer, becomes transformed into a rapid agitation of the molecules of the mass which arrests it.

Heat sustains, moreover, a relation to light. That they are closely connected, our commonest experience teaches us all; but how closely, the world has only in late years learned. Light, too, is but a vibration as it comes to us through the transparent ether which, as a medium, connects our world with the stars; and hence it is easy to

* Tyndall; Lectures on Heat.

conceive them as analogous states of matter. The vibrations of heat have only to be sufficiently increased, and the heated body begins to report itself to our eyes as a luminous one. The lower temperatures are dull and faint in their gleam, but as the temperature rises, that is, as the rapidity of the motion increases, the light grows more intense, till the agitated and quivering mass glows with the white light which represents the intensest heat, and almost forbids our direct vision.

Light also stands in similar relations to mechanical force. The sudden arresting of a mass in rapid motion, produces not only heat but light. Tyndall states that the impact of one of the solid projectiles of the great Armstrong guns, upon a target at Shoeburyness, sometimes produced not only heat, but a flash of light so distinct as to be visible by broad daylight.

Now these two great classes of agencies to which I have referred, the electro-chemical force on the one hand, and that of light, heat and mechanical force on the other, were next drawn into mutual relation. It was found that not only would the voltaic pile develop heat, as in many arrangements it does to a very high degree, but that certain applications of heat would also develop the phenomena of electricity; and soon the thermo-electric pile was devised as by far the most sensitive instrument for the measurement of heat. Thermo-electricity has now become a very important branch of physics; and we have in this name another indication of the general progress of the identification of all these varied agencies.

The exact mechanical equivalent of heat has been determined after a vast amount of careful experiment and measurement, by Joule in England, and by Mayer in Germany; so that it now seems possible to calculate, on the one hand, the amount of heat which would be produced by the arrested motion of any moving mass, and on the other the amount of matter which could be put in motion by the extinction of a given amount of heat. The amount of force required to raise a weight of one pound through a height of one foot, called the *foot-pound*, is the unit.

Thus all these different forces are found to be but varied manifestations of the same great agency. They are different kinds of motion, produced by a force which is not many and diverse, but one and simple. The varying phenomena are identified with one another through their common relation to the general fact of motion, of the specific kinds of which we have yet much to learn. What is the

particular kind of motion which constitutes heat, and how it differs from that of light, and how from that of electricity, we do not know, nay, are perhaps far from knowing; but we seem pretty well assured that these different kinds of movement all sustain a common relation to the mechanical motion of a mass, and are substantially convertible into one another; and this is what is now meant by the *convertibility*, or the *correlation*, of the forces; they are all interchangeable forms of a single force.

I pause a moment in view of a generalization so interesting, and so comprehensive. For the co-ordination of a vast number of remote and apparently unrelated facts, no other generalization which science has reached since the great discovery of Newton, seems to me so remarkable. The varied phenomena of nature had been already grouped into distinct classes, and arranged with all the method of a scientific order; the generalization which embraces them all, is, therefore, the comprehension of a whole body—nay, of *the* whole body of the physical sciences, under one most general principle. The explanation which this generalization affords is equally happy. The result is no simple registration of phenomena, according to that superficial view of induction which theoretically denies to science anything more than the office of mere observation. More true to the high aims of the intellect itself than to the demands of that insufficient theory of procedure which is honored under the name of induction, the men of science have concurred with unwonted unanimity, first, in referring the phenomena observed, in each several department, to the ground which alone can afford a satisfactory view of them; and then in embracing all these distinct branches of knowledge under what we may, with some reservations, call a universal expression. The consequence is, the discovery of a law, on the one hand, so comprehensive as to include the immense and varied body of natural phenomena, and, on the other, so profound as to furnish explanation of the whole vast mass. Each phenomenon is an intelligible result of some modified operation of the one great and universal Force of Nature.

It is a point of great interest that, in this wide formula, science seems to have reached the extreme limit of her inquiries. When these specific forces have once been thus grouped and united, no further advance in generality of expression is possible. The problem has been reduced to its very simplest form of statement. These navigators on the great sea of the unknown, set out by different and

even opposite courses; but, sailing thus in contrary directions, they have at length come in view of each other; their discoveries have compassed the globe, and the whole orb of knowledge stands disclosed in all the simple harmony and unity of truth.

If there is something painful in the idea of having reached the limit of research in so great a sphere of inquiry—in hearing, as it were, the last word of science in regard to the great expansion of her thought, we may, at least, feel that it enables us the better to pursue the course of those reasonings upon which the noblest minds have always been intent. If the problem is solved, we may the more justly inquire for the bearing of the solution upon the great theme of our present inquiry.

This brings us to the question, for the sake of which I have entered into this account of the doctrine of force, as at present held. What is to be the bearing of this great discovery upon the theistic view of the universe? What is to become of our conception of God, when the phenomena of nature are all referred to general or universal laws, and these are affirmed to be the manifestations of one comprehensive, controlling, and universal force, operating through the unnumbered ages of past time? Let us endeavor to trace the subject to its issues.

Before, however, we can have much hope of gaining any idea of the bearing of this discovery, we shall need to inform ourselves somewhat more particularly of the specific character of the force thus indicated. Under what form of thought is it to be properly conceived; or, scientifically speaking, what is its law?

Here it is first to be observed, that the general expression which we have obtained is not absolutely universal. We identify several, perhaps many, of the forms of force known to us, but we have no reason from that fact to assume that we have thereby identified them all. Each of the forces included in our generalization has, as its marked characteristic, a definite relation to physical motion; we may find reason to conclude that there are other forces which have no such relation. In that case we should be acting wholly without our warrant, if we should insist upon stretching our generalization so far as to include them. There is a group of forces which together govern the motions of atoms in space. Physicists have thus far recognized no others; but I can hardly be wrong in saying that the force by which an atom resists the compression which would crush it out of exitence, is one of a wholly different order,

and has no relation whatever to motion, either molecular or mechanical. Perhaps, too, other forces, relating not to the constitution of matter, but to the operations of the mind, may be arrived at, which equally refuse to come within the generalization.

In speaking, therefore, of the convertibility of forces, I beg that it may be observed that I speak with a limitation, and refer only to the motive forms of force—to those general and diffused agencies which pervade the universe and give movement to the atoms which compose it.

Of these forces, then, I may observe that, in the case of several of them, science has ascertained the existence of a common law which affords us a deeper insight than we gain by any other means, into their interior nature. The great law which governs, and expresses, the diffused operations of gravitation, has been already determined to be that of the inverse square. Now, it is quite remarkable that the same law has been proved to be the one which governs the attractions of electricity, and also, on independent grounds, of magnetism. We should have been at liberty to infer as much from the common nature of these forces, but it so happens that the proof of this community is less clear in the case of gravitation than in that of some of the others. On the ground, however, of this common law, we may feel emboldened to identify them all, and to conceive their general action as altogether analogous to the well known operations of this familiar agent.

Let us suppose, then, the universal prevalence of such a force as gravity is ascertained to be, viz., one that corresponds in intensity to the mass of the matter involved, and which varies inversely as the square of the distance. That gravity exists under this law is, perhaps, the best ascertained of all physical truths. It pervades the universe through all its spaces, and it reaches and governs each minute particle of matter. Now, we shall find that the simple supposition of the prevalence of such a force will give us, as a result, the existence of the other phenomena—of many of them, at least—which our observation has recognized as other forms of force. Gravity is abundantly familiar to us as connecting the mass of the earth itself with the objects upon its surface; and Newton extended it to the moon, and determined first her motions, and then the motions of the celestial bodies generally, to be governed by the same force. But when we come to reason about the force which governs the relations of physical objects to each other, we fail to recognize

it with any similar distinctness; indeed, we have failed to recognize it at all. Yet even here it exists, and our observation, if nice enough, could not fail to distinguish it.

The proceedings of the Royal Astronomical Society (vol. xiv) contain a very interesting account of the exact methods employed to ascertain, and to measure, the force of gravity between bodies of moderate size on the surface of the earth. Dr. Maskelyne had previously determined the fact that the attraction of a precipitous mountain influences the direction of a plummet hanging near it, and swerves it from its true perpendicular position; but more precise and extended experiments were required, for the production of accurate standard measures of length, which had been determined upon by the British government; and the work was undertaken by the highest scientific skill. A cylinder of lead was cast, with the utmost care to obtain it pure and make it uniformly dense; from this were turned, with exactest nicety, two spheres of lead of some twelve inches diameter, for attracting-balls. Then two small balls were added with delicate torsion suspenders, the motion of which was to be accurately observed. But, alas! after weeks and months of observation, only the most irregular and inconsistent results were obtained. It was found, upon inquiry of the most successful continental observers, that the slightest changes of temperature between the bodies were sufficient to invalidate the results. It was necessary to deposit the apparatus in an underground apartment, so as to obtain as nearly as possible, an absolute uniformity of temperature, and to observe it by means of a telescope through a glass door, in order to detect the slight modifications which the attraction exhibited. Still, with such minute care, aided by whatever suggestions science could furnish, observations were obtained which authenticated, and measured, the force of gravity as an actually existing and appreciable thing, which exerts an agency between all the masses of matter on the surface of the earth.

Supposing, then, that such a force exists and operates everywhere around us, let us endeavor to trace it to its results. Recollect that, by the very supposition, its effect must be faint at any considerable distance, save when the masses which attract each other are very great; but that a force which follows this law, though faint at considerable distances, becomes large when the particles are near, and, after it once becomes perceptible, grows immensely with every additional reduction of the distance. Half the distance will give four

times the force of attraction; a reduction to the tenth part, will magnify the force one hundred times; and an approximation which reduces the distance to the hundredth part, will raise the force to ten thousand times its original amount.

Upon this law, a particle brought into close proximity with any small mass must show a faint attraction for it, like that which exists between the movable particles of a fluid and the inner surface of a tube partly immersed in it. Precisely such is the force which we call capillary attraction. Next, bring two molecules into still closer proximity to each other, and the result must be a still more powerful attraction, corresponding to that force of mechanical aggregation which forms the ordinary masses of our less dense minerals, like clay or chalk. Let them come still nearer, into a proximity measured by the minute intervals of thousandths or ten-thousandths of an inch, and the attraction increasing in a proportionate degree inversely, not as the distance but as the square of the distance, must develop a force equaling the highest that we know—that which governs the combinations of chemistry, and effects the cohesion of masses of homogeneous matter, like the pure metallic elements iron, lead, or gold.

We have only to suppose that the atoms of matter are determined by some such cause as heat, to stand at different distances from each other, and the supposition of one general force, varying as the inverse square of the distance, will give us as the inevitable theoretical result, different manifestations or rather different degrees of attraction, corresponding to most of the well-known forces which exist around us. Thus, gravitation will be but the attraction of masses for each other at considerable or great distances; capillary attraction will be the attraction of particles by some mass to which they are very nearly approximated; mechanical cohesion will correspond to the relation of particles brought into much closer proximity—a force of far greater strength, corresponding to the square of the diminished distance; and the highest of all known forces must inevitably result from bringing the atoms of matter into the closest possible approximation to each other. Our general theory must involve these varied results, when viewed in connection with the varied distances at which we conceive the particles to stand; and the doctrine spreads a beautiful simplicity and clearness of conception over the whole field of these varied forms of nature's action. The general and diffused forces of the universe may thus be all con-

ceived as only varied forms of gravity, acting under its single, simple, and beautiful, law of the inverse square.

Nor is there any reason to doubt the actual existence of such vast amounts of force in these minute relations. Tyndall abundantly illustrates the immense power of these molecular forces. He describes the manner in which an iron cylinder, half an inch thick, is burst with ease by the expansion of a small quantity of water freezing within it; and mentions that metallic cylinders of double that thickness, are unable to resist the force with which a small voltaic battery effects decompositions.

The same writer, speaking of the forces involved in the molecular changes which accompany chemism, says:

"The energy of the forces engaged in this atomic motion, as measured by any ordinary mechanical standard, is enormous. I have here a pound of iron which, on being heated from 32° to 212° F., expands by about $\frac{1}{800}$th of the volume it possessed at 32°. Its augmentation of volume would certainly escape the most acute eye; still, to give its atoms the motion corresponding to this augmentation of temperature, and to shift them through the small space indicated, an amount of heat is requisite which would raise about eight tons one foot high. Gravity almost vanishes in comparison with these molecular forces; the pull of the earth upon the pound weight as a mass, is as nothing compared with the mutual pull of its own molecules. Water furnishes a still subtler example." * * * "Suppose a pound of water heated from $3\frac{1}{2}$ C. or 39° F. to $4\frac{1}{2}$ C., that is, one degree; its volume at both temperatures is the same; there has been no separation of the atomic centers, and still, though the volume is unchanged, an amount of heat has been imparted to the water sufficient, if mechanically applied, to raise a weight of 1,390 pounds one foot high."*

Pursuing the illustration, he estimates the force employed in combining one pound of hydrogen with eight pounds of oxygen, to form water, as "equal in mechanical value to the raising of 47,000,000 pounds one foot high." The substance would then be in the form of vapor, and, "to condense this to a liquid, would require a power equal to 6,718,000 foot-pounds; and still, further, to bring the fluid water to the form of ice, would require a force of 993,564 foot-pounds."

"I think," he observes, "I did not overrate matters when I said that the force of gravity was almost a vanishing quantity, as exerted

* See Tyndall's Lectures on Heat.

near the earth, in comparison with these molecular forces." Strangely enough, Tyndall does not here recognize these molecular forces as being themselves but manifestations of the force of gravity exerted between atoms, though elsewhere he shows that the conception is not altogether an unfamiliar one to him. But, translating his statement into its more appropriate terms, I will call upon you to observe the immense energy with which gravity unites the particles when once they are fairly brought within the scope of each other's attraction. They are held to each other with a power that we can hardly estimate. The force requisite to unite one pound of hydrogen with eight of oxygen, and condense them to ice, can be estimated only by millions—not less than 55,000,000 of pounds! Most truly does the same writer say on another occasion, "The force with which bodies expand when heated is quite irresistible by any mechanical appliances that we can make use of. *All these molecular forces, though operating in such minute spaces, are almost infinite*" (mark the word) "*in energy.*" Here, again, I must venture to put in a correction. It is not "*though*" operating, but *because* operating in such minute spaces; it is because the atoms are brought into such close approximation, that the amount of force is so immensely great. That any mass of matter, brought indefinitely near another, must experience a vast force of attraction, is a simple consequence of the law of the inverse square; but as it is only these minute atoms which can be so closely approximated to each other as to feel the full power of each other's attraction, it is between them only that we find this extraordinary intensity of force. The sphere of their operation is reduced to the most contracted limit; but within that sphere they are boundless. The *atomic* forces of nature are the *great* forces, and, in precise accordance with the fundamental law, they are vast, just in proportion to the nearness of the objects on which they act; and within the inappreciably small distances of which we have spoken, the force must be of necessity, immeasurably great.

This is the limit to which the physical observer carries his reasonings. But the process cannot stop here. It is an accepted doctrine of our natural philosophy that, in every union, chemical or mechanical, with which we are acquainted, the particles still stand at appreciable distances from each other; and still more recently it begins to be affirmed, as an indispensable element of our physical reasonings, that the particles of every solid body are permanently in some kind of regulated motion or vibration. The spaces in which these mole-

cular movements take place, must be considerable when compared with the magnitudes of the moving particles themselves. The physicist sometimes startles his hearers by the statement, that the immense orbits of the heavenly bodies are not more vast in comparison with the diameter of the planets, than are these inter-atomic spaces in comparison with the dimensions of the vibrating atoms. The distances, therefore, which separate the particles of a solid from each other, even in the closest unions that we know, are not only appreciable, but must be regarded as relatively very great. What, then, must follow when the approximation becomes more complete — when the atoms stand, perhaps, much nearer than in our closest chemical combinations? Especially, what must follow when the distance is absolutely overcome and annihilated, and the particles of matter are brought into absolute contact with each other? Plainly, by all laws of reasoning, the force must in that event become *infinite*. As the distance diminishes, the force increases; and this by a rate more rapid than the diminution to which it corresponds, even as the inverse square of the diminished distance. Increasing, therefore, by this advancing rate, the growing force must rapidly outrun all measurement; and with the cessation of all interval between the particles, it necessarily surpasses all finite quantity, and becomes absolutely infinite. The conclusion may be surprising, even startling; but one fails to discern any consideration which should lead us to call it in question.

And why should we be unwilling to admit it? Did we not just now hear our great expounder of physics—Tyndall himself—say that these forces are "almost infinite?" But why "almost?" The limitation is altogether gratuitous. "Not only almost," a greater authority than he once said, "not only almost, but altogether." If they are *almost* infinite at the minute distances which we know, what are they, what must they be, when the distances are annihilated, and each atom is given up to the full force of the attraction which embraces and holds it?

Every established principle of reasoning—even of our most exact and mathematical reasoning—points to this single conclusion. When of two terms inversely related to each other, one wholly disappears, the other can be expressed by no sign but that of infinity; nor can we refuse to admit the result without impeaching the very principles upon which all reasoning in physics depends.

Such, then, must be our general inference from the prevalence of

the admitted law of gravitation throughout the universe—that an infinite force is exerted in connection with every particle of matter.

Of the objections which may be suggested to this result, I cannot here stop to take particular account. It is clear, however, that no one of them can possess any weight against our conclusion, which is not of equal validity against the law of gravitation itself. It may be said that that law is valid for perceptible distances, but that we do not know it to be so at the infinitesimal distances to which our reasoning refers. But it is evident that this is imposing upon a known law, a modification which has no ground but our ignorance. The atom is wholly beyond the sphere of observation, and we have no right to assume, without some necessity to dictate the procedure, that within the inter-atomic spaces, the law is at all different from what we discern it to be in those which are open to our observation.

Another objection to the conclusion which I have affirmed, arises from the belief that the supposition of a repulsive force becomes necessary, to account for the continued separation of particles, which must otherwise inevitably be crowded together into a perfectly compact and dense mass. To this it may be replied, that it is not repulsive force that causes smoke to rise from the earth in the atmosphere, or a cork in water; neither does a specific force of that kind need to be supposed, to preserve the equilibrium of the planetary system. Perhaps, therefore, some other supposition may be found adequate for a similar result in the case of the particles of matter. Possibly enough the established system of molecular motions, already referred to as existing in every mass of matter, as heat, or some similar form, may be found quite sufficient to prevent the apprehended consequence of a crush of all material particles into a common center.

I can only say that, upon a somewhat careful consideration, I have found no objections that seem to be of any very decisive weight against the conclusion which I have been led to form. For the present, therefore, that conclusion must stand unopposed as the only rational result of accepted scientific principles; and we are driven to admit that the surest of our physical determinations—the law of the inverse square—implies the existence of an infinite force governing each particle of matter.*

* The only objection which it seems important to discuss is that which arises from the idea that the force of attraction between any two bodies must be measured from their centers of gravity; and that its maximum cannot be developed by any contact of mere surfaces.

The next thought to which our reasonings conduct us is, that this infinite is one of a very high kind. It is not the simple infinite which would be furnished by the law of a force increasing inversely as the distance; though that, too, would give an infinite as the result in every case of the actual contact of particles. But this is an infinite of what mathematicians call *the second* order, involving an immensely higher degree of force, and corresponding to the geometrical laws which necessarily govern the diffusion of any emanation.

It operates, too, in every possible—nay, in every conceiveable—direction, from every particle as a center; so that we have both an infinite of intensity, and an infinite of direction, involved as consequences of our original admission of the universal prevalence of the law of the inverse square. It becomes evident, upon consideration, that this astonishing intensity of force cannot be the endowment of the atom of matter with which, to ordinary view, it seems to be connected. We come then next to inquire, what is the seat of this infinite force to which we have been brought? In what does so vast and amazing a power inhere, and to what does it belong?

It is here to be observed that force is not an independent and substantive entity; it cannot be conceived as capable of existing alone. It does not float free in the universe. By its very nature it exists, always as a quality of some substance. As motion never can be conceived as real, without something to be moved, so force never can

This objection rests on the demonstration of Newton, that the sum of all the attractions of a number of particles free to move, is precisely the same as if the whole were con centrated at the center of a spherical mass. From this datum it is inferred that the maximum of force could be developed only by contact of the centers, and as these must forever be separated by the sum of the two radii, the absolute maximum never can be reached.

To any such reasoning, however, it may be replied, that the center of gravity is not an objective fact, but only an abstraction of the mind itself; it is a conception formed for the simplification of the mechanical and astronomical problems which present themselves, but by no means an objective reality. The resultant of two impulses upon a body, is motion in an intermediate direction, and this may be treated and reasoned of precisely as though the impelling cause were one. But the philosopher who should argue on that supposition as an actual fact, might not be farther from the truth than is he who conceives the familiar abstraction of the center of gravity to be the real point of the development of force.

Moreover, Newton's demonstration, on which the objection is based, has reference to the particles of a mass *not subjected to the disturbing influence of any other attraction.* For matte r under that condition, his conclusion is valid. But when the mutual attraction of *two* such masses is in question, the conditions of the problem are altered. The center of gravity for each, is no longer at the absolute center of the mass, but approaches that side on which the attracting body exerts its influence. The conception, therefore, of two centers of gravity, coincident with the centers of the two masses, is materially inaccurate. As the two masses approach each other, the two centers of gravity may, perhaps, be more and more removed toward their surfaces, in the line which joins the centers of the two bodies, till, at the moment of contact, they may even coincide in the point of junction and constitute only a single mass.

It seems, therefore, altogether legitimate to say that, even upon the supposition of the reality of the center of gravity as the point of maximum energy, the objection cannot be decisively maintained.

be conceived except as the attribute of some substance to which it belongs and on the existence of which its own existence is dependent. Force is evermore the quality or attribute of something to which it belongs, or in which it inheres.

To the inquiry above suggested, we are not yet in a position to return a complete answer. All that we can now say is, negatively, that there is no reason to think that such an astonishing amount of force can be the endowment of the elementary atom. The minute particle cannot possess this infinite force. It would violate every law of our thinking to imagine such a thing. The atom cannot be the infinite; cannot possess the infinite. This minimum of possible existence cannot exert the maximum of power. We must look elsewhere for its seat.

Nor can we, on other grounds, admit such a supposition, since we should, in that case, be forced to concede the existence of many such infinites. If each particle were to be conceived as capable of exerting an infinite force, we must at once admit an indefinite number of such infinites, a conclusion against which all philosophy revolts. There can be no such multiplicity of infinites. The idea is at war with all simplicity, and with all comprehensiveness, of thought.

A more precise consideration of this subject will greatly contribute to support the conclusion that the force is not inherent in matter at all. Indeed, it is by no means *in* matter that we find the force which is the subject of our reasonings. The very existence of the force is indicated to us, not by anything in the particle itself, but simply by its motion, by its change of position in reference to other particles. Of no other relation does the theory take cognizance than this alone. Heat is a mode of motion, and heat is identical with light, and identical with electricity, magnetism, etc. All these manifestations are referable to the movements of atoms in space, and gravitation does but sum up all these movements in the one comprehensive formula, which states the mode in which this force varies with the varying masses and distances of the objects upon which it acts. No one of these forces has any recognizable relation to the constitution, or gives us the least insight into the structural relations, of the atoms which they govern. They relate exclusively to the movements of these atoms with reference to one another. The fact, the law, and the specific character, of these changing place-relations—these are all that our several sciences profess to ascertain for us. In light, we have the measured vibrations which give us, by their motion, the

sense of color; in heat, we have a mode of motion, less rapid and regular, but still only motion; in electricity we have attraction and repulsion; in magnetism polarity—that is, motion of particles and of masses, from or toward the poles of a magnet; in the voltaic circuit, besides the two last mentioned, we have the transfer of particles from the positive to the negative pole, and chemical combination and decomposition; and in gravitation—that comprehensive form which, as I have maintained, sums up all the rest—we have only the movement of particle and mass toward a center. Everywhere we have motion simply, mere change of position and combination; and motion is always *ab extra*. Every motion of matter that we know, is from some external source.

Now, in all these forms of motion there is no indication whatever of anything inherent in the particle, and no question of any such thing. The particle simply changes its place and its arrangement with others. It is attracted or repelled—combined or detached—permanently or transiently, and with more or less intensity; this is all. We have simply the evidence of a force which controls the movements of atoms in space—a force everywhere present throughout space, and impressing motion upon the particles of matter in accordance with laws—or more properly, with *a* law, since all are one—of great simplicity and comprehensiveness.

But there is no indication that this force, which ever holds matter in its mighty and comprehensive grasp, is resident in the atoms which it controls. All that we ascertain of it shows it rather to be pervasive, and universal. It reaches *from* atom to atom, and on, from atom to more distant atom; from mass to mass; from planet to planet; from system to system. It fills the minute spaces which separate atom from atom; it spans the chasm between orb and orb; it reaches from system to system of the galactic mass, to which systems and suns belong—it stretches onward and outward, and above and below—through ether and media, and whatever else, till it fills the very immensity of nature, as the separated particles of matter never do and never can.

Now, surely, the force which is known to us solely as determining the position of particles in space, and as impressing movement upon them, is not to be conceived as residing in the particles themselves. It exists no more truly within the atoms than it does without. It has nothing to do with their specific constitution or character, and does but impart impulse and motion to them. It is not confined and

limited, belonging to this atom or to that, but pertains to something which is all-pervading, and which occupies every void space in which a material atom exists and moves.

Why limit it to the particle which it controls and adjusts, when it exists in every minute void, and extends throughout every vast reach, of the boundless universe to which our observation can penetrate? Evidently such a limitation is needless and gratuitous. The cosmos is no chaos of ten thousand conflicting forces, seated in as many separate atoms of matter, and forming a combination which is but the resultant of unnumbered oppositions of independent powers. It is a harmony, and it is ONE. It is one, by virtue of its great, simple and comprehensive law, which is the harmonious operation of a single grand universal and infinite force, pervading and controlling its every part. To this result, the doctrine of the unity and the correlation of the forces, inevitably conducts us.

And is it not thus that the thoughtful mind has ever imagined it to be? An Infinite Force, everywhere present, impressing itself upon every particle of matter, giving law to the universe and imparting motion to its otherwise dead masses and forms—to that the human mind has ever been trying to lift itself—it has been the aspiration and the aim of every noble soul. To that science, after so long wandering amid facts, and phenomena, and laws, now seems making its way, and coming to support the aspiration she has sometimes seemed to suppress and smother.

After long dealing with forces and principles that seemed as diverse and conflicting as the forms and phenomena of matter, science gains a glimpse, nay a conviction, that beneath all these varied forms there is one general system of laws, simple and far-reaching; and drawing her breath with a wonder that is half delight and half awe, she exclaims, "*The forces of nature are all one.*" Yes; so the devout mind has always understood it to be; all forces in this vast scheme of nature are manifestations of one; all life and movement have one great Author.

Pondering yet more profoundly this great generalization, science still further announces that this universal force is a force inherent, not in the particles of matter, but in something which pervades the universe, giving movement and law to all matter, and establishing harmony throughout all nature. And what is this but the recognition of an immaterial ground and source of all the phenomena of the world about us! One comprehensive and universal Force, of infinite

intensity, of unlimited extent, of immaterial nature. Such is the issue to which the doctrines of the convertibility and correlation of the forces are bringing the scientific mind of our day. Shall we not accept the conclusion which does but translate into a scientific formula the long familiar language in which theology has ever proclaimed one infinite, omnipresent, and spiritual, Lord of the universe, and say with satisfaction and joy, that surely the long conflict of scientific and religious thought must be approaching its end, when both acknowledge the universal sway of the one infinite force, which is at the same time, the All?

Perhaps, however, a conclusion so gratifying may seem a little premature. Is it quite certain that the acknowledgment of a universal force, must carry with it the certainty of so complete a harmony of thought in these two departments of reasoning? Let us look somewhat more carefully into the nature of our apparent result.

Our conclusion is that the agencies of nature are to be referred to one comprehensive force. But surely force is not God. In order to any very distinct appreciation of that conclusion, we need to determine somewhat more accurately what our conclusion amounts to.

What, then, is force?

This inquiry is one which physical science, with all its effort at the accurate measurement and general identification of the forces, has hardly taken up for investigation. She has been content to rest in a vague acceptance of the conception as something generally known, with little attempt to ascertain its precise content of meaning.

One writer has indeed attempted a definition, but the inadequacy of the result becomes painfully apparent upon a moment's consideration. "Force," he declares, "is motion." As much motion as there is, so much force there is, and no more. But call it by what name you will, it must surely be admitted that there is force where there is no motion. The stones of an arch press with a very positive and unmistakable force, upon the abutments; but if the arch is sound there is no motion, and can be none. This is identifying the agent with one of the familiar phenomena by which it manifests itself, and through which we recognize it; but the phenomenon of motion is not the force which causes the motion. The meaning of the word *motion* is abundantly clear; in its original and physical sense, it denotes simple change of place; and this is not what any man ever meant by the word force. Force has indeed a relation to motion; it is even that which produces motion; but it is not itself motion.

When we look upon a handful of gunpowder we may well believe that there is an immense force connected with those little black grains; but to say that there is any motion of them, except by a loose metaphor, would be affirming what our senses of sight and feeling positively deny.

This attempted definition, however, is interesting, inasmuch as it is the frank expression of a great embarrassment in physical philosophy. Strictly, it is plain that force is not mere motion; and yet it becomes clear, on reflection, that it is only as expressed by means of motion, that physical science can recognize force at all. The energy — if it is more satisfactory to the scientific reasoner to describe it by that term—out of which motion arises, science cannot distinctly recognize as separate from the motion itself; not because the two are indistinguishable, but because there are no physical terms for the description of the hyper-physical source from which motion originates.

So far is it from being true that force is conceived as identical with motion, it is not as motion that, even in physical nature, force is revealed to us. We become acquainted with it not as motion, but as resistance to our own voluntary effort. When, for instance, I attempt to break a stick, or to tear a piece of paper, I become acquainted with the cohesive force which holds atoms together, not by any motion in it, or in them, but simply by its resistance to my own exercise of power. The type of force is not motion, but *resistance*, which is *rest**—the balance or equilibrium of forces. So, I become acquainted with gravity as a force, not by the observation of motion, but by the resistance which it offers to my own attempt to uphold an unsupported body.

Indeed, I do not become aware of the force which I myself exert in connection with my physical system, through any observation of the motion which it produces. When a man, in walking rapidly, comes in contact with some fixed object, and receives a blow, or a shock, from the collision, the physiologist tells him that we put forth a great deal more force in our ordinary movements than we are at all aware of. This internal exertion of force becomes so familiar, in its ordinary exercise, that we often do not notice it; and the motion which is produced by it fails entirely to suggest to the mind our own very active exertion, until some resistance rudely awakens us to a knowledge of the very energetic efforts which we are almost unconsciously putting forth.

* *Resto*, or *re-sisto;* not to move, but to stand.

With the exception of this one attempt, I know of no effort to define force by any physicist; and this is simply a confusion of motion with the condition on which it depends. The omission is so great that it naturally suggests inquiry. How is it that scientists, so much concerned with the subject as to have studied very laboriously the relations of each form of force to the others, and to have reached the grand generalization which unifies all the specific forces of nature, have never made any serious effort to define this ultimate element in which all their researches terminate? How is it that they have never felt the need of an accurate determination of the meaning of the one word of transcendent importance, and of constant occurrence, in all their inquiries? All the movements of nature, we are told, are due to one force; and this force is forever indestructible, and its amount forever equal and undiminished in the universe; but when we ask, "What is force?" we have no answer, and nobody has ever thought of the propriety of framing an answer, or has any answer to give.

The only explanation of so great an oversight, is to be found in the fact that the conception of *force is one of those universal ideas which belong of necessity to the intellectual furniture of every human mind.* It is one of those simple and essential elements of our knowledge, which are imparted to us by the very action of our own minds; and which, therefore, may well be assumed as universally known. But force is not an object of the senses, and no examination through any organ of sense, or through any instrument of observation, can detect its presence. It is not phenomenal; does not reveal itself through any manifestation, but belongs to the interior nature and constitution of things. Hence, though all physical science supposes it, and all scientific reasonings assert or assume its existence, science can give no account of it by any physical characters. It has no form or color for the eye, and no sound for the ear; it has no odor, nor feel, nor taste. It is neither solid, fluid, nor gaseous; it does not crystallize in any one of the six regular systems of the mineralogist; it does not combine according to any chemical formula; it finds no place in any latest list of the sixty or seventy known elements. Physical science, therefore, has no means of defining it. The definition must be looked for in quite another direction. The question, what force is, our physical philosophy has no means of answering; and hence it is no scandal, nor reproach, that she has never undertaken to answer it. That deter-

mination must come from a nicer analysis than either the qualitative, or the quantitative, method of chemistry.

All this is simply saying that the conception of force is metaphysical, rather than physical, and is derived from the mind and not from matter. It cannot, therefore, be analysed in either the wet or the dry way; unless, indeed, the metaphysical analysis of abstract ideas should be decided to belong, as I think *has* sometimes been suggested, to the latter method.

What, then, is force, metaphysically? How do we become acquainted with it in the sphere of the mind? To what extent is it known to us as an element of our psychology?

To these questions, the answer is not difficult. We become acquainted with force as an element of our own personal experience. We are conscious of the exercise of something which we call energy, force, or power, in our own mental states. Throughout that sphere, we are familiar with the great conception of *action;* and action is the exercise of force. The mind is constitutionally endowed with a power of action; and this power of our spiritual nature is what we mean by force. Force, then, is the active nature of a cause; that quality by virtue of which it acts, and produces effects. It is one of the elements of our very being—an essential quality of our intellectual nature. We are often conscious of the exercise of this activity, and recognize a power in ourselves by which we are capable of exertion and effort.

This exercise of our activity we become aware of in all the forms of perception and consciousness. Thus we hear some sound, but are unable to distinguish it clearly, and to decide upon its character; and we listen with attention, with *an effort*, to discriminate it from other sounds, and to learn its true nature. So, too, in vision, we examine by the eye with a similar strain of attention. In our ordinary visual perceptions, the phenomena are so obvious that we are not conscious of any effort in observing them. Hence metaphysicians have often been disposed to speak of the mind as passive in its recognition of physical objects. But when the object is very minute, or the characters indistinct, what a consciousness of effort there is in our determinations! The botanist, for instance, who examines with his glass the obscure organs of some small flower, how strenuously does he exert his whole faculty of vision, to make sure of the facts upon which his classification depends!

The same remarkable circumstance occurs, also, in our purely mental action. What efforts do we sometimes make of memory, to recall

a lost fact; of conception, to grasp a vague idea, and reduce it to distinctness; of thinking, to trace out conclusions and consequences! In every form of intellectual action we find frequent occasion to exert our power of knowing—that inherent and universal quality of our active mental being.

Now, in all these varied experiences of our consciousness, we observe and recognize the idea, and the fact, of power or force. It is originally known to us as a quality of the mind, ever acting, ever revealing itself in this inner sphere. Here we become acquainted with force, and learn to discriminate and to understand. It is the correlative of action; it is that by which we can act; and action is simply the exertion of force. *Here*, we know something about it, as in physics proper we do not; and we distinguish it from all other things by the clearest, surest, and most familiar, experience.

Now, with this knowledge of force, psychologically gained, we are able to understand ourselves when we speak of force in the world without us. When asked, "What is force?" we cannot, indeed, reply in terms of physical science, or physical quality, but, in the language of our mental experience, we can give ready and decisive answer. It is the capacity of acting, the power of exertion, which we ourselves possess, and which we exercise in all our actions. Action, you will observe, is our only word to describe a phenomenon of the mind; we can designate our mental changes only as actions. The word derives its whole meaning from our inward experience in consciousness; and its explanation, when applied to any physical fact, can be found only by going back to the original sphere of its occurrence, and noting what it meant there. All actions of material things have a meaning derived from the action of the mind, with which they are conceived to be in some real analogy. Force, too, has in our experience the same hyper-physical origin, and the same intellectually determined signification; and, apart from this, the word means nothing, and its use describes nothing. It denotes a fact of deeper meaning than the mere phenomena of our observation. It describes that profound and productive energy which underlies all the phenomena of the universe. Force is the energy of a cause; and the universal force, to which all specific forces and movements are to be referred, is the power, ever present, and everywhere active, of one comprehensive and universal Cause.

The bearing of this conclusion upon natural theology is immediate, and important. Every force is the quality of some cause; but it is

primarily known to us as the endowment of the mind. The only cause of which we have any direct and immediate knowledge, is the mind itself; the only force, the force of our own minds. Anything, then, which becomes known to us through the exercise of force is presumably a mind. I have already shown that the forces which govern matter are not the attributes of the material particles themselves; they are one, and however seemingly different, they are but varied forms of the force-activity of one universal Cause. But as the only force known to us is the attribute of an intellectual being, the presumption is, that the comprehensive force of the universe is of the same kind; it is the attribute of an intellectual and spiritual being like ourselves. Such is the presumption, for such is the only force the existence of which we positively know; and this fact throws the burden of proof on him who denies the intellectual and spiritual character of this force. It is contrary to the analogy of our knowledge to suppose the existence of any other force than such as we know; and whoever does it, assumes the obligation of proving the reality of what he assumes.

But, though it would be legitimate to do so, we need not rest here. The advance is easy to whatever conclusions the theological hypothesis requires, though, under the limitations to which such a paper as this is confined, I can only indicate very briefly, the general nature of the reasoning which establishes them.

This universal Cause, then, or to use scientific language, *the one force, is*, in the next place, *creative*. It has shaped and moulded the cosmical system. Of creation, in the sense of an absolute production of matter, science knows nothing. Whence matter came she does not assume by any methods of her own, to determine. The only creation that she knows, is the shaping of the celestial orbs, and the adjustment of their positions and motions; and these are due to the one force which we have described and identified. She tells us how in the beginning matter existed, "without form and void"—a limitless and universal mist—an omnipresent star-dust throughout space; how gravity, and heat, and the other forms of force began to condense, and to unite, the severed particles, and to aggregate them into perceptible magnitudes; how, as the process went on, revolving rings and spheres were formed throughout the celestial spaces; and how they became consolidated into the rolling orbs of our visible heavens. All this is familiar to us as the teaching of the nebular hypothesis; and it shows that the force of the universe is creative and construc-

tive, and has given to the system of things its orderly and beautiful motion, its profound mathematics, and its elegant geometry.

A similar method of reasoning will disclose to us the intelligence of this creative power. We infer that the Author of so much that our intelligence comprehends and delights in, must be itself intelligent. Nor in this inference, do we at all depart from the accepted methods of scientific investigation.

Hitherto, and before the establishment of the doctrine of the convertibility of the forces, phenomena of each specific kind had to be separately investigated, and the facts of each class to be organized into a separate science. Those facts could not, at that stage of investigation, be referred to any recognized agency, or be classed with any other phenomena. They necessarily formed a group by themselves, and were treated as the subject-matter of a distinct science. Thus electricity, galvanism, heat, and the other physical agencies, formed so many separate departments of knowledge, and gave rise to so many independent sciences. In each one of these the method adopted was that of determining the character of the unknown force, from that of the phenomena. These, classified and arranged, gave the law of the mysterious agent with which we were dealing, and indicated to us all that we could know of its nature, and of its methods of operation. Thus, in gravity, we had the conclusion of a force, the law of which was that of the inverse square; in magnetism, the inference was of a force acting in curved lines from one pole to the other of a magnet. Universally, the character of the unknown agent was reached by inferences derived from the observation of its phenomena of force-activity.

We adopt the same method in our teleological reasonings. We study the phenomena as our observation discerns them, and they indicate the law of the unknown force to be that of *intelligence.* It is the force of something which acts, as we do, from a perception of reasons and for the accomplishment of ends. It has all the characteristics of an intelligent and spiritual nature, like that of the human mind.*

Did time permit, it would be interesting to proceed, and under the same scientific sanction, to develop yet further the characteristics

* How simply, and yet how forcibly, has Cicero expressed this idea, in those elegant writings which have given instruction and delight to the cultivated minds of every subsequent age:

"Quumque sint in nobis consilium, ratio, providentia, necesse est deos hæc ipsa habere majora; nec habere solum, sed etiam his uti, in maximis et in omnibus rebus." See *The De Natura*, Lib. II, 79.

of this creative and general Agent. I might show that it is a free and elective force, acting under the law, not of necessity, but of adaptation and choice, and possessing herein the eminent characteristics of a spiritual being; and that beyond even this, it is manifested to us as a moral and benevolent being. It is a PERSON; a being who is percipient not only of mechanical exigencies and contrivances, not only of ideas and laws, but of moral relations, and of benevolent and holy ends. The creative force of nature belongs to a Spiritual Being—is the attribute of an Infinite God.

Such, then, is the general method which our reasonings must follow; and such are the conclusions which arise from the new aspect of the physical philosophy of our day. Surely they are of a most interesting kind. Science comes to recognize force as the basis of all life and motion in the universe, and she decides that the force is forever *one*. But force is spiritual and intellectual, and the necessary, or at least the probable conclusion is, that the one force is that of a spiritual being. Force, however, is an intellectual conception, and can be known only by a study of the mind. Science, therefore, is not the study of nature alone; it embraces as well, the study of man. Science cannot assert the existence of force, without some knowledge of the human mind from which alone the idea of force is derived. All true science, therefore, involves both the knowledge of nature and the knowledge of man; it includes the study of mind, as well as of matter. A philosopher may pursue either; but he can have no complete knowledge of what he investigates, without borrowing from the other department of investigation. If the scientist would understand that force which is the great result of his discoveries, he must learn it in, and from, the mind, in which alone we discern its character, and learn its reality: if the metaphysician would understand the abstractions with which he deals, he must study them in connection with their manifestation in nature. All true science implies a knowledge both of nature and of man; and the knowledge of nature and the knowledge of man, together, give us, beyond all contradiction, beyond all mistake, the knowledge of a universal, infinite force, residing in an intelligent, moral, and personal Being; or, in other words, the knowledge of God.